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FIELD STRESS DETERMINATIONS AT SELBAIE MINE, QUEBEC

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ELLIOT LAKE LABORATORY

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MICROMEDIA

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FIELD STRESS DETERMINATIONS AT SELBAIE MINE, QUEBEC

by

B. Arjang*

ABSTRACT

Field stress determinations were conducted at Selbaie Mine, of Selnor Inc., in northwestern Quebec. Elastic strain recovery measurements were carried out on the 70, 180 and 290 m levels, with an overcoring technique using CSIRO hollow inclusion triaxial strain cells.

The stress determinations resulted in the following:

Depth (m)	Stress Components (MPa) Standard errors in brackets			Principal Compressive Stresses (MPa) Magnitude and Orientation		
	Horizontal E-W	Horizontal N-S	Vertical	Major σ1	Intermediate σ2	Minor σ3
70	0.80	1.97	1.55	3.37	1.40	-0.45
	(.14)	(.10)	(.04)	323°/-19°	353°/68°	236°/10°
180	8.82	5.30	4.36	9.26	5.05	4.17
	(.20)	(.10)	(.08)	110°/-10°	192°/-0.8°	286°/-80°
290	13.31	7.45	6.40	14.69	6.93	5.55
	(.11)	(.05)	(.05)	110°/-12°	011°/-35°	036°/52°

The measured vertical stress indicated slightly lower values than the predicted pre-mining overburden stress.

Generally, the maximum stress is directed nearly perpendicular to the orebody while the intermediate stress parallels the orebody.

The direction of the current stress field appears to be in agreement with the predominant orientation of geological structure at the test site.

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DÉTERMINATION DES CONTRAINTES DU CHAMP À LA MINE SELBAIE (QUÉBEC)

par B. Arjang*

RÉSUMÉ

On a déterminé les contraintes du champ à la mine Selbaie de la Selnor Inc., dans le nord-ouest du Québec. Des mesures de la relaxation des déformations élastiques ont été faites aux niveaux 70 m, 180 m et 290 m par saignées par trou de sonde à l'aide d'extensomètres triaxiaux CSIRO à inclusion creuse.

Les résultats des déterminations sont les suivants:

Profondeur (m)	Composantes des contraintes (MPa) Erreurs types entre parenthèses			Contraintes de compression principales (MPa)		
	Horizontale		Verticale	Grandeur et orientation		
	E-W	N-S		Majeures 1	Intermédiaires 2	Mineures 3
70	0,80 (,14)	1,97 (,10)	1,55 (,04)	3,37 $323^{o}/-19^{o}$	1,40 $353^{o}/68^{o}$	-0,45 $236^{o}/10^{o}$
180	8,82 (,20)	5,30 (,10)	4,36 (,08)	9,26 $110^{o}/-10^{o}$	5,05 $192^{o}/-0,8^{o}$	4,17 $286^{o}/-80^{o}$
290	13,31 (,11)	7,45 (,05)	6,40 (,05)	14,69 $110^{o}/-12^{o}$	6,93 $011^{o}/-35^{o}$	5,55 $036^{o}/52^{o}$

Les contraintes verticales mesurées sont légèrement inférieures aux contraintes géostatiques prévues avant la mise en chantier de la mine.

En règle générale, les contraintes maximales sont presque perpendiculaires au corps minéralisé, et les contraintes intermédiaires parallèles à celui-ci.

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La direction de l'actuel champ de contraintes semble correspondre à l'orientation prédominante de la structure géologique à l'emplacement de l'essai.

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INTRODUCTION

As a part of the cooperative project between Selbaie Mine (Selnor Inc.) and CANMET/MRL, ground stress determinations have been carried out at the Selbaie Mine.

Three test sites for ground stress measurements were selected on the 70, 180 and 290 m levels, in the dacitic rock of the footwall. These sites were away from the main mining developments; minimizing the effects of mining-induced stress concentrations around the test area. In addition, the tests were commenced at distances from the walls of the openings which were greater than one or two diameters.

The overcoring technique using the CSIRO hollow inclusion triaxial strain cell was employed (1) and eight tests were conducted.

GEOLOGICAL SETTING

The Selbaie Mine, a base metal mine, is located about 95 km west of Matagami, Northwestern Quebec. Figure 1 shows the regional geology of the area and the location of the mine. The geologic setting of the Selbaie deposit reflects a complex history of intermittent faulting and extrusive activity. The ore zone is contained in dacitic rocks and has a general N-S strike and a dip of 40°-50° East. The most prominent structural features are a main fault or 'shear zone' on the footwall, the orebody contact and three discontinuity sets (two steeply dipping, and one sub-horizontal).

FIELD MEASUREMENTS AND TEST SITE DESCRIPTIONS

Ground stresses were determined on levels 70, 180 and 290 m below surface in a fine-grained dacitic rock of the footwall strata. The test sites were selected away from intense fracturing, faults or shear zones. The rock material at the sites was homogeneous. A general mine section and the test

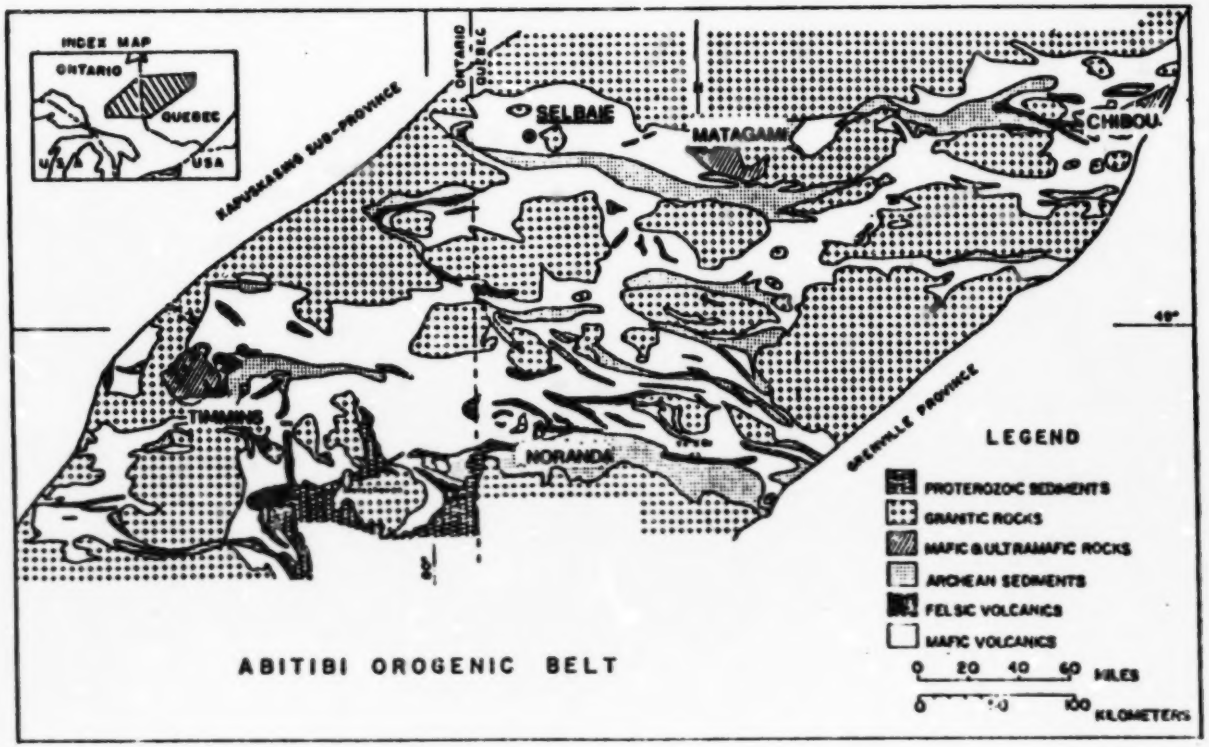


Fig. 1 - Regional geology (2), and the location of Selbaie Mine.

levels are shown in Fig. 2. Four holes were drilled from the mine openings, which were 3 to 3.6 m square. The locations and directions of the drill holes are shown in Fig. 3, 4 and 5. The test holes were drilled at inclinations of 4° to 14° above horizontal. Overcoring was carried out at a speed of ½ to 1 cm/min. The rock temperature was approximately 7° to 8°C, and a drill water temperature of 6°C was recorded.

Of the eight tests attempted, four were unsuccessful because of core breakage, cutting of the read-out cable of the strain cell during overcoring (SB1-2, SB1-3 and SB4-2 tests), and poor bonding of the strain cell (SB2-1 test). Erratic readings of some strain gauges were observed. These were subsequently rejected from the stress calculations.

The first drill hole (SB1) on the 290 level had to be adandoned after about 8 m of drilling because a water-bearing fracture was intersected. A second hole (SB2) was drilled from the same set-up, 0.45 m above the first hole and in the same direction.

On the 70 and 180 levels the tests were carried out approximately 40 m away from the main fault on the footwall orebody contact. In the vicinity of the test location on the 290 level no major weakness planes were exposed.

Close to the test sites, structural discontinuities were measured along the drift walls. Two near-vertical discontinuity sets and one sub-horizontal set prevailed as shown in Fig. 6, 7 and 8. The northeasterly oriented discontinuities showed indications of shearing in a few cases.

LABORATORY TESTING

Unreliable strain readings as a result of instrument or strain gauge malfunction, or fracturing of the overcored sample, can be detected during the field measurements. The less obvious parameters which may affect the test

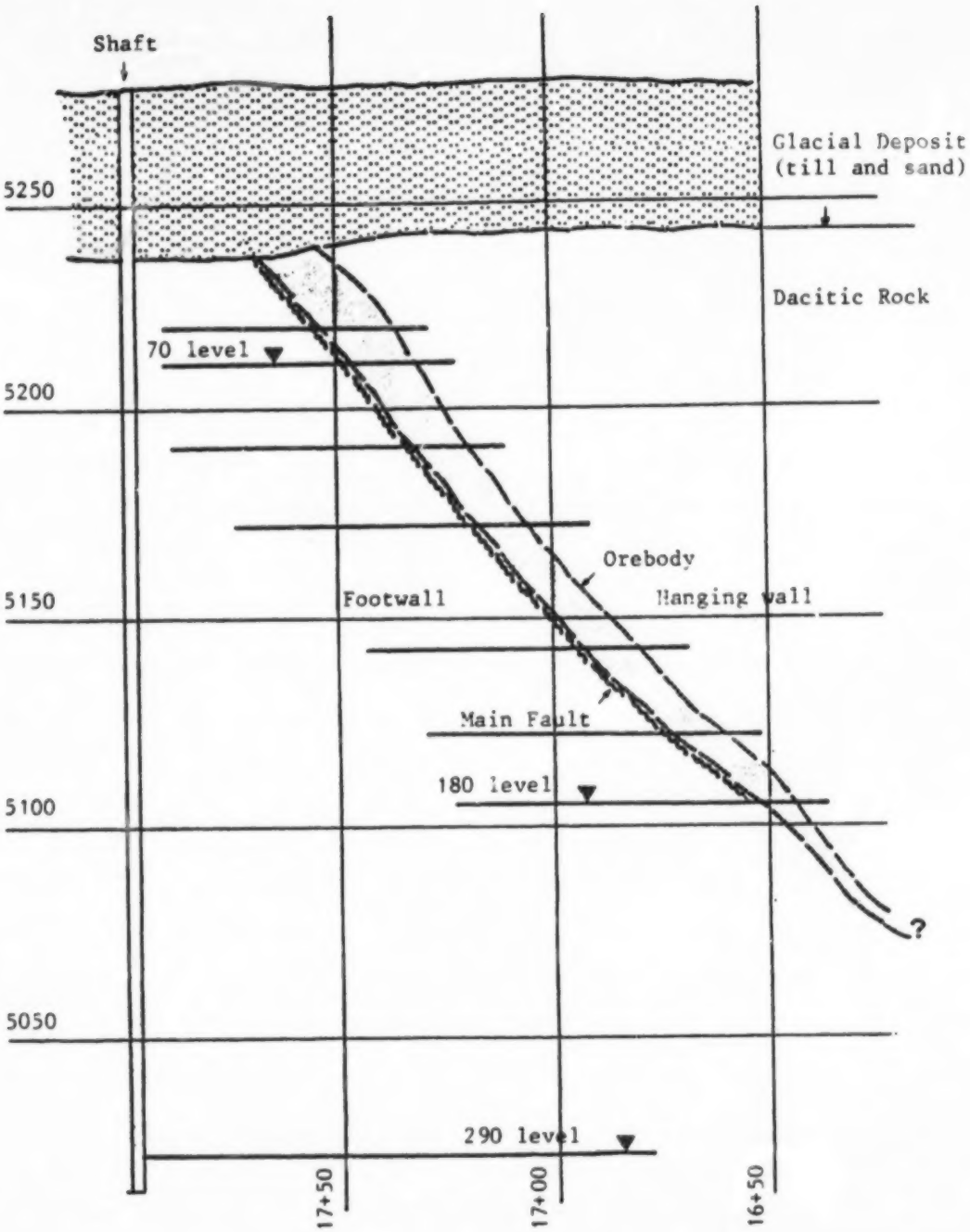


Fig. 2 - Generalized section of Selbaie Mine, test levels and location (▼)

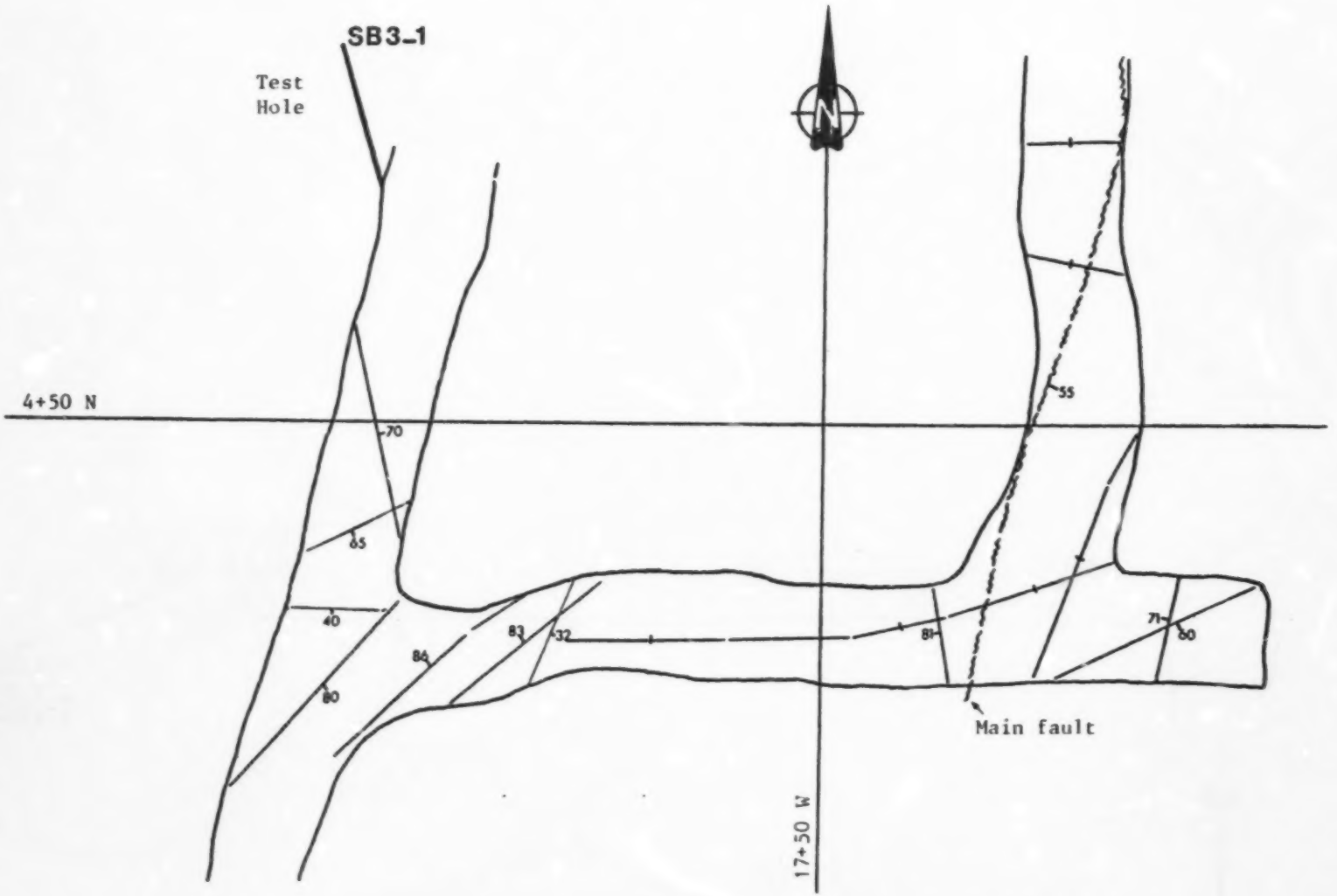


Fig. 3 - Stress determination site and test hole location on the 70 level (scale 1:250).

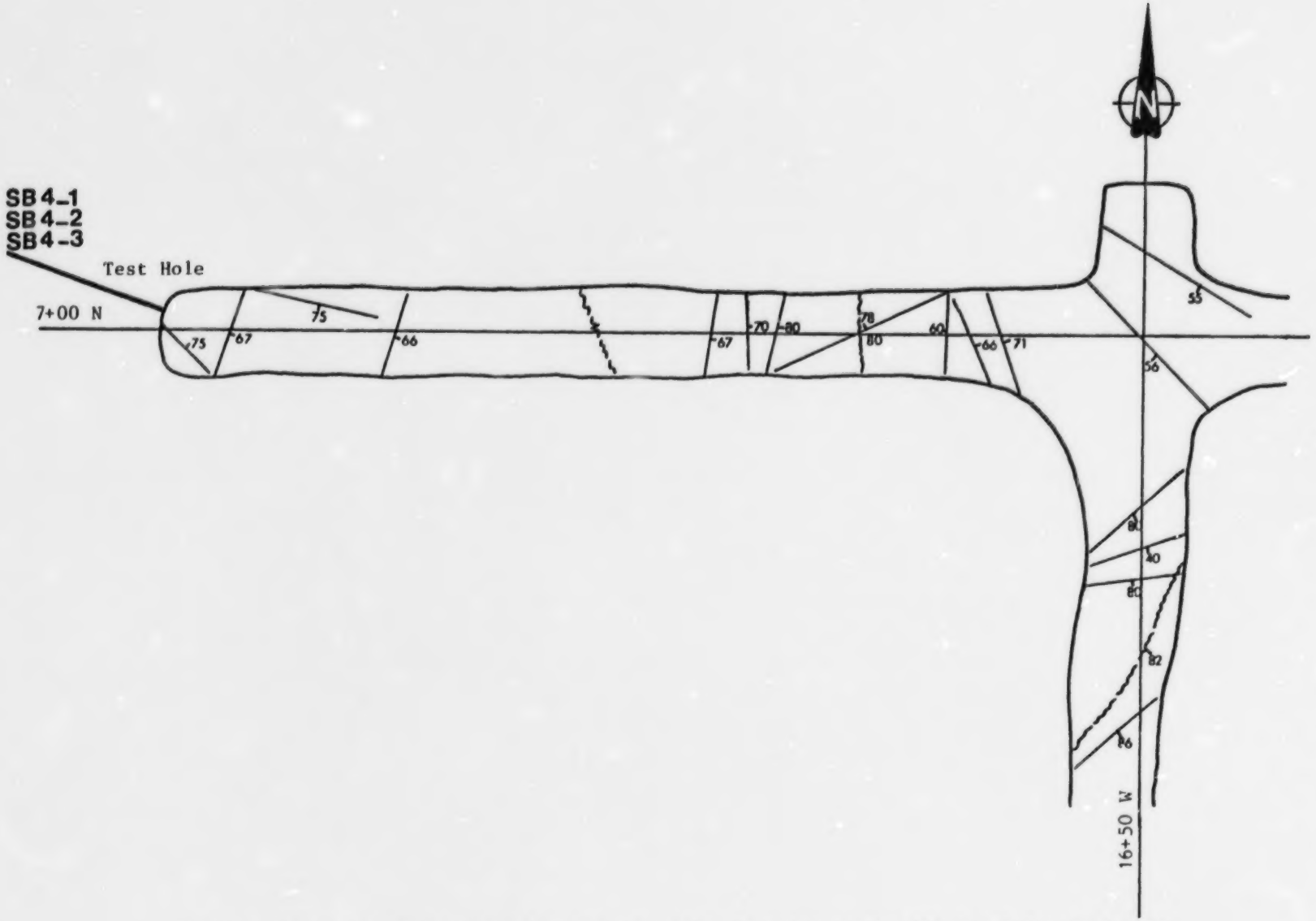


Fig. 4 - Stress determination site and test hole location on the 180 level (scale 1:250).

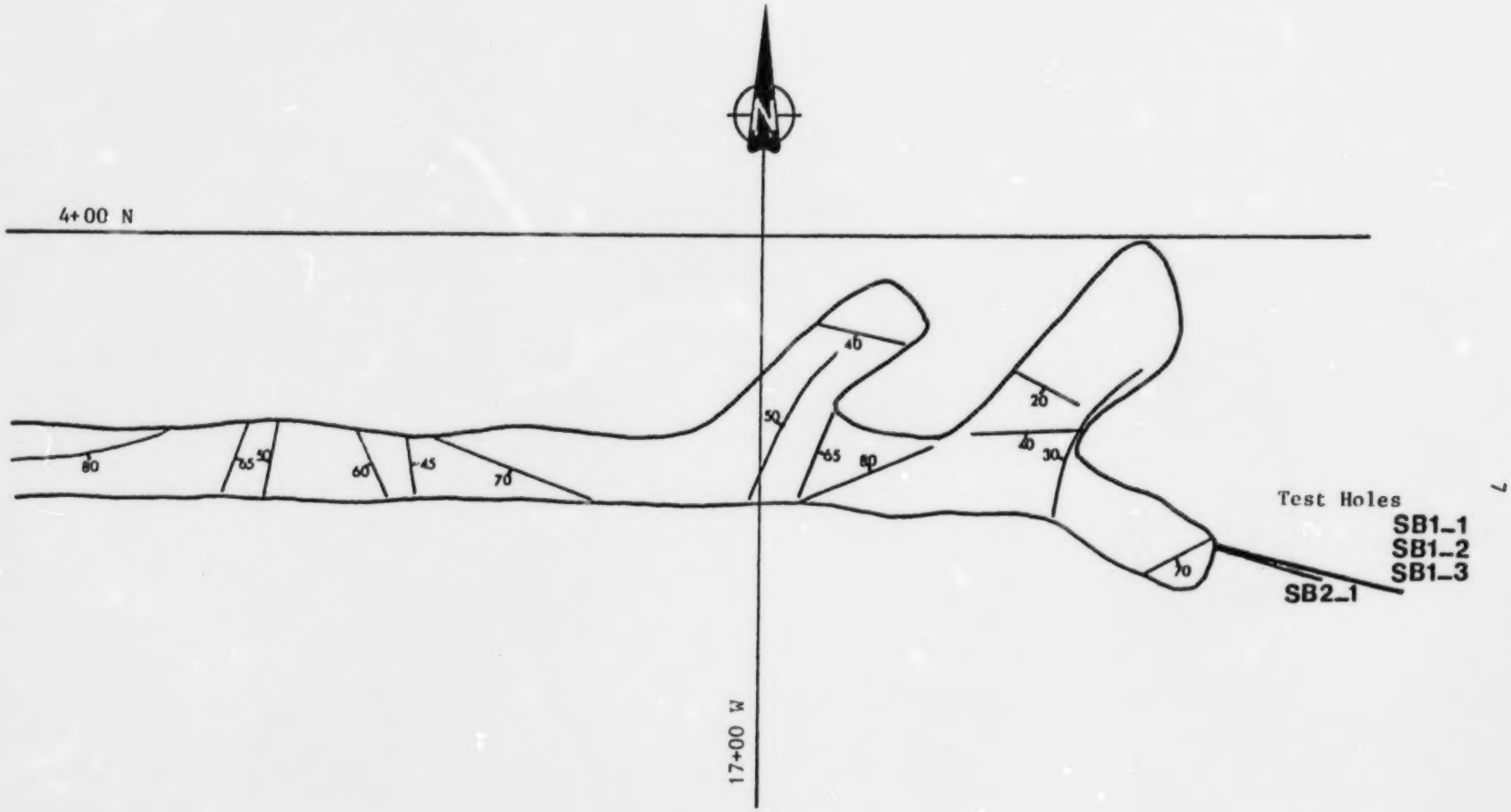
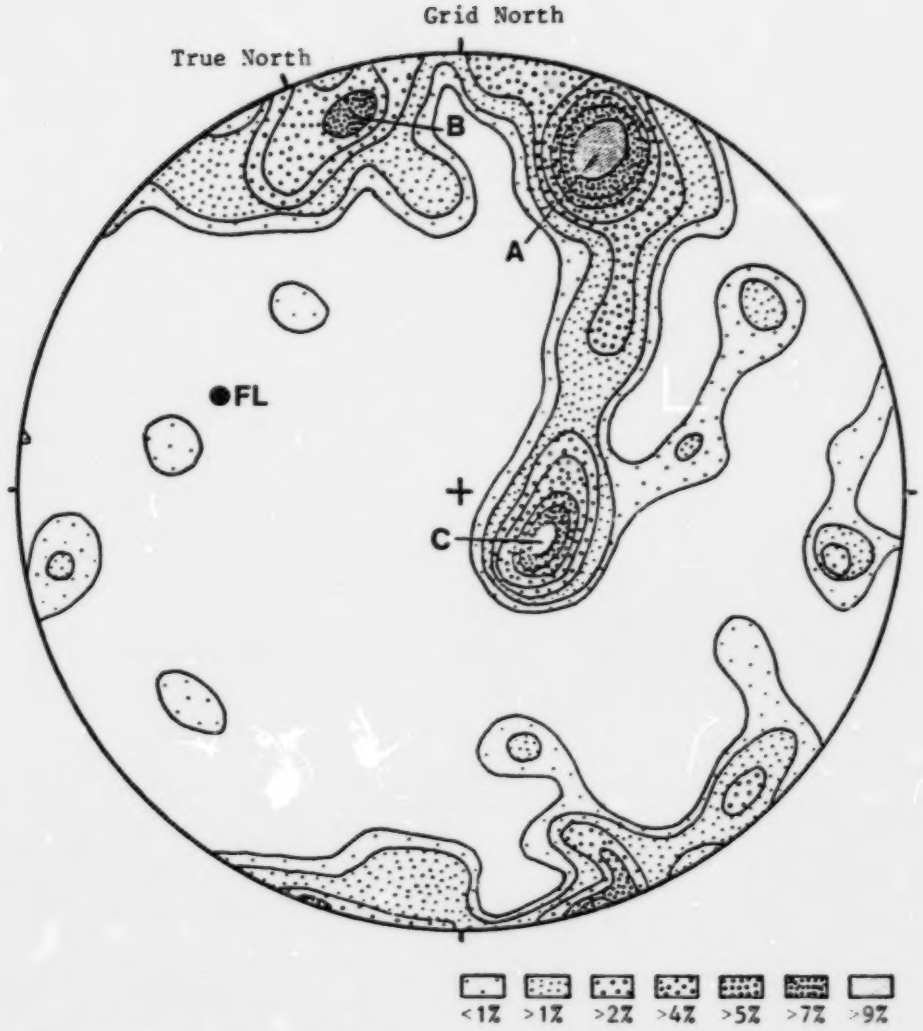


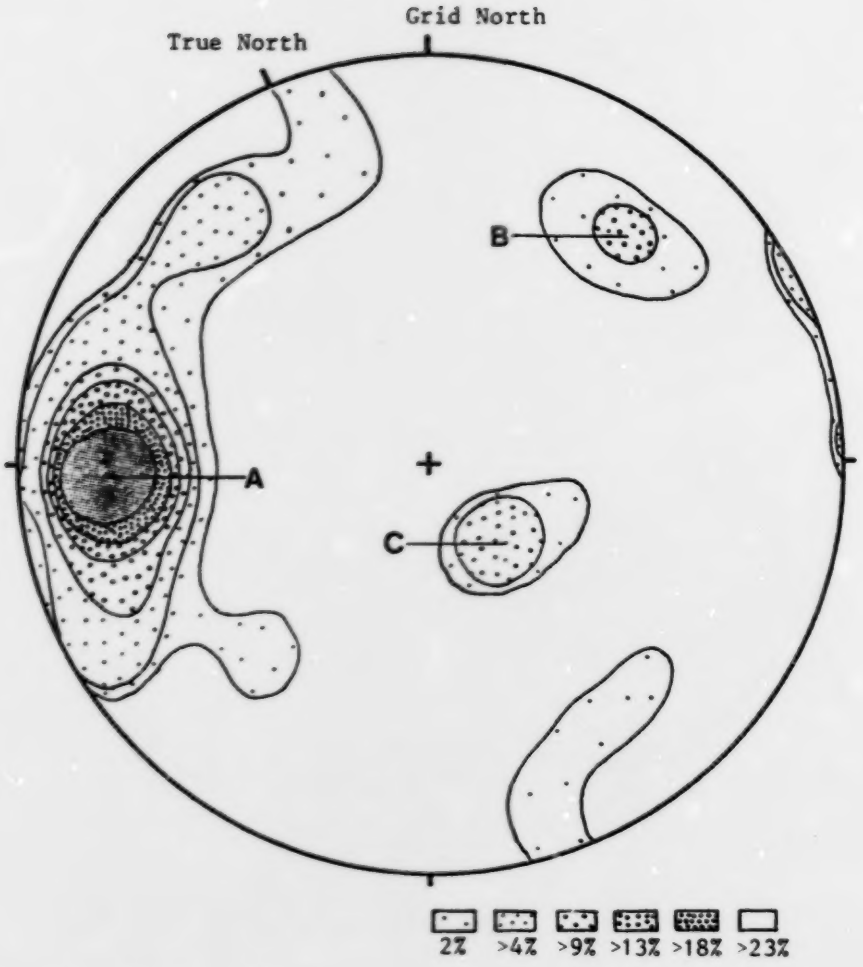
Fig. 5 - Stress determination site and test hole locations on the 290 level (scale 1:250).



Mean Orientation of Discontinuities
(Dip direction/dip)

Set A : 202°/75°
Set B : 166°/80°
Set C : 301°/18°
FL : 110°/50° - main fault on F/W, O/B contact.

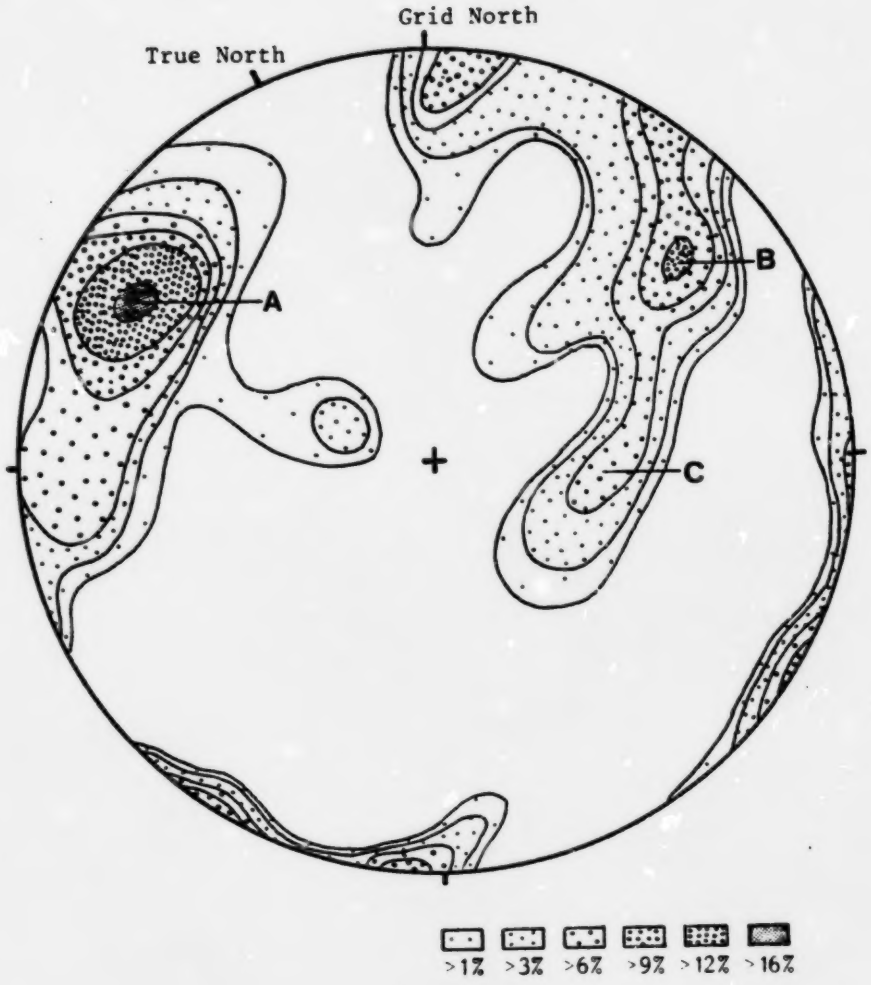
Fig. 6 - Stereoplot diagram of discontinuities on F/W, 70 level (approximately 100 m south of test site); contours in percent per 1% area for 141 observations.



Mean Orientation of Discontinuities
(Dip direction/dip)

Set A : 086°/67°
Set B : 244°/63°
Set C : 340°/21°

Fig. 7 - Stereoplot diagram of discontinuities on F/W, 180 level in the vicinity of test site; frequency contours in percent per 1% area for 43 observations.



Mean Orientation of Discontinuities
(Dip direction/dip)

Set A : 120°.70°
Set B : 216°/65°
Set C : 272°/36°

Fig. 8 - Stereoplot diagram of discontinuities on F/W, 290 level in the vicinity of test site; frequency contours in percent per 1% area for 62 observations.

results and provide unsatisfactory data were checked during quality testing in the laboratory.

Elastic modulus and Poisson's ratio values were obtained in the field with a biaxial chamber. Each core was subjected to a radial pressure of up to 17.24 MPa, and readings were taken for each gauge at 3.44 MPa intervals. Gauge responses were checked and the readings of circumferential and axial gauges were used for calculation of elastic modulus and Poisson's ratio. Some results obtained were not representative of the rock material encountered in the test site. The values obtained in the test environment for elastic modulus were from 59.31 to 73.79 MPa, and for Poisson's ratio, were from 0.35 to 0.47. These values were checked in the laboratory. Representative solid core samples (average diameter 142 mm) were selected and prepared with a length to diameter ratio of 2.5. The samples were right circular cylinders with the ends ground parallel to ± 0.04 mm. Each sample was fitted with two pairs of strain gauges at mid-height; one pair oriented axially and the other in the transversal (circumferential) direction. Each core sample was axially loaded and unloaded with maximum pressure of 20 to 27 MPa. Readings of gauges during unloading were used to calculate elastic moduli and Poisson's ratios. The values obtained for elastic modulus in the range of 62.82 to 69.72 MPa, and for Poisson's ratio of 0.21 to 0.29, were taken for the stress tensor calculations.

The overcoring response of the strain gauges is important in interpreting the validity of a test. The gauge response may reflect improper installation, faulty bonding, or a faulty gauge. In order to determine the quality of the bond between the epoxy and the borehole surface, axial sectioning of the overcores was carried out. It was found that, in some cases, the epoxy contained minor air bubbles. This is not believed to have influenced the strain readings, although test No. SB1-2 was rejected because of poor bonding after laboratory evaluation. The bonding problems that were experienced could

be related to the presence of moisture in some pilot holes.

In some tests the thermal equilibrium between rock and drill water might not have been achieved before or during overcoring. This condition resulted in erratic response or in considerable drifting of some gauges, such as in the SB4-2 test.

STRESS CALCULATIONS

The computer program 'OVERCORE' was used (3) for the calculation of stress components, and the magnitudes and orientations of principal stresses. The composite elastic constants, the test hole bearing and dip in the mine grid system, and the strain recoveries during overcoring were the input data for the stress determinations. The microstrain difference for each gauge was taken approximately between 10 before and 15 cm after the strain cell centre line, (in some cases after the readings had been stabilized).

The elastic strain recovery obtained during overcoring and the test performance are given in Table 1. The plots of gauge responses and the changes in microstrain are shown in Fig. 9 to 14. Table 2 provides the stress components, and Table 3 shows the magnitude and orientation of the principal stresses with respect to geographic coordinates. The orientations (bearing/dip) of the principal stresses in stereographic projection are illustrated in Fig. 15, 16 and 17 for each test site.

The CSIRO hollow inclusion strain gauges provide nine strain values, oriented in eight different directions. This results in some redundancy. Therefore, a solution of best fit, based on a least square analysis, can be carried out. The most outlying strain reading can be detected and rejected from further calculations.

The judgement regarding the relevance of the results is a summary of the quality of the data, based on field and laboratory tests, and statistical analysis.

Table 1 - Strain recovery data from triaxial strain cell measurements the 70, 180 and 290 m levels, Selbaie Mine.

Depth (m)	Test No.	Hole Bearing/dip(*)	Setting Depth from Collar (m)	Elastic Strain Recovery (με) 1	2	3	4	5	6	7	8	9	Elastic Modulus (MPa)	Poisson's Ratio	Comments on Test Performance
70 :	SB3-1	343/-4	5.92	-79	18	19	37	30	-35	42	70	18	62.82	0.21	FC,C8,AC
180 :	SB4-1	290/-6	5.98	52	59	1	120	54	106	73	41	92	69.72	0.25	S,IO,GB,AC
	SB4-2	290/-6	7.14	36	60	5	197	108	122	-(x)	34	106	69.72	0.25	S,CB,GB
	SB4-3	290/-6	7.84	106	183	146	154	176	173	116	172	155	69.72	0.25	S,IO,GB,AC
290 :	SB1-1	103/-7	1.81	168	122	196	108	187	177	151	182	164	64.89	0.29	S,IO,GB,AC
	SB1-2	103/-7	5.90	Test unsuccessful											IO,PB
	SB1-3	103/-7	8.10	Test not completed											CC
	SB2-1	105/-14	4.55	37	196	41	100	36	66	93	133	143	64.89	0.29	S,IO,PB

(*) Bearing in degrees clockwise from Grid North positive; dip in degrees (dip from horizontal, positive down).

(x) Malfunction of instruments, no gauge response; omitted from stress calculations.

Comments on test performance:
S = Stable readings; CB = Core broken off; IO = Intact overcore;
FC = Fracture through strain cell; GB = Cell well bonded; IP = Improper installation;
PB = Cell poorly bonded or air bubble in epoxy; CC = Strain cell cable cut during overcoring;
AC = Accepted strain recovery for stress tensor calculation.

Table 2 - Stress components and stress ratios from triaxial strain cell measurements on the 70, 180 and 290 m levels, Selbaie Mine.

Depth (m) Test No.	Setting depth from collar (m)	Stress Components (MPa) (Standard errors in brackets)						Stress Ratios ($\sigma H/\sigma V$)		
		Horizontal		Vert.	Shear Stresses					
		σ E-W	σ N-S	σ	τ N-S/E-W	τ E-W/V	τ V/N-S	K_{N-S}*	K_{E-W}	$K_{Ave.}$
70 : SB3-1	5.92	0.80 (.04)	1.97 (.10)	1.55 (.04)	-1.67 (.05)	0.63 (.03)	-0.30 (.04)	1.27	0.51	0.89
180 : SB4-1	5.98	6.57 (.13)	3.43 (.05)	1.97 (.06)	-0.66 (.05)	-0.86 (.08)	0.19 (.03)	1.76	3.38	2.57
SB4-2	7.14	11.33 (3.08)	4.66 (.81)	2.09 (.85)	-1.56 (1.04)	-0.74 (1.03)	0.04 (.43)	2.22	5.42	3.82
SB4-3	7.84	11.08 (.27)	7.21 (.15)	6.57 (.11)	-1.58 (.13)	0.23 (.13)	-0.20 (.06)	1.06	1.64	1.35
290 : SB1-1	1.81	13.31 (.11)	7.45 (.05)	6.40 (.05)	-2.62 (.05)	-1.88 (.05)	0.00 (.03)	1.66	2.07	1.61
SB2-1	4.55	5.87 (.07)	3.55 (.03)	4.60 (.04)	-0.26 (.03)	1.68 (.05)	0.60 (.02)	0.72	1.27	0.99

* $K_{N-S} = \frac{\sigma N-S}{\sigma V}$; $K_{E-W} = \frac{\sigma E-W}{\sigma V}$; $K_{Average} = \frac{K_{N-S} + K_{E-W}}{2}$

Table 3 - Magnitude and orientation of principal stresses from triaxial strain cell measurements on the 70, 180 and 290 m levels, Selbaie Mine.

Depth (m) and Test No.	Principal Stresses (MPa) Bearing/Dip* σ_1	σ_2	σ_3	$\frac{\sigma_1}{\sigma_1}:\frac{\sigma_2}{\sigma_1}:\frac{\sigma_3}{\sigma_1}$	$\frac{2\sigma_1}{(\sigma_2+\sigma_3)}$
70 : SB3-1	3.37 323/-19	1.40 353/68	-0.45 236/10	1:0.41:0.13	7.09
180 : SB4-1	6.86 110/-10	3.30 192/-0.8	1.78 286/-80	1:0.48:0.26	2.70
SB4-2	11.73 102/-4	4.32 012/-3	2.03 067/85	1:0.36:0.17	3.69
SB4-3	11.66 290/-3	6.81 025/-56	6.56 018/34	1:0.58:0.56	1.74
290 : SB1-1	14.69 110/-12	6.93 011/-35	5.55 036/52	1:0.47:0.37	2.35
SB2-1	7.04 273/-35	3.59 325/42	3.19 206/29	1:0.50:0.45	2.07

* The bearing is the angle in degrees positive clockwise from Grid North (Grid North is 22.67° east of True North); the dip is the angle in degrees positive down from horizontal.

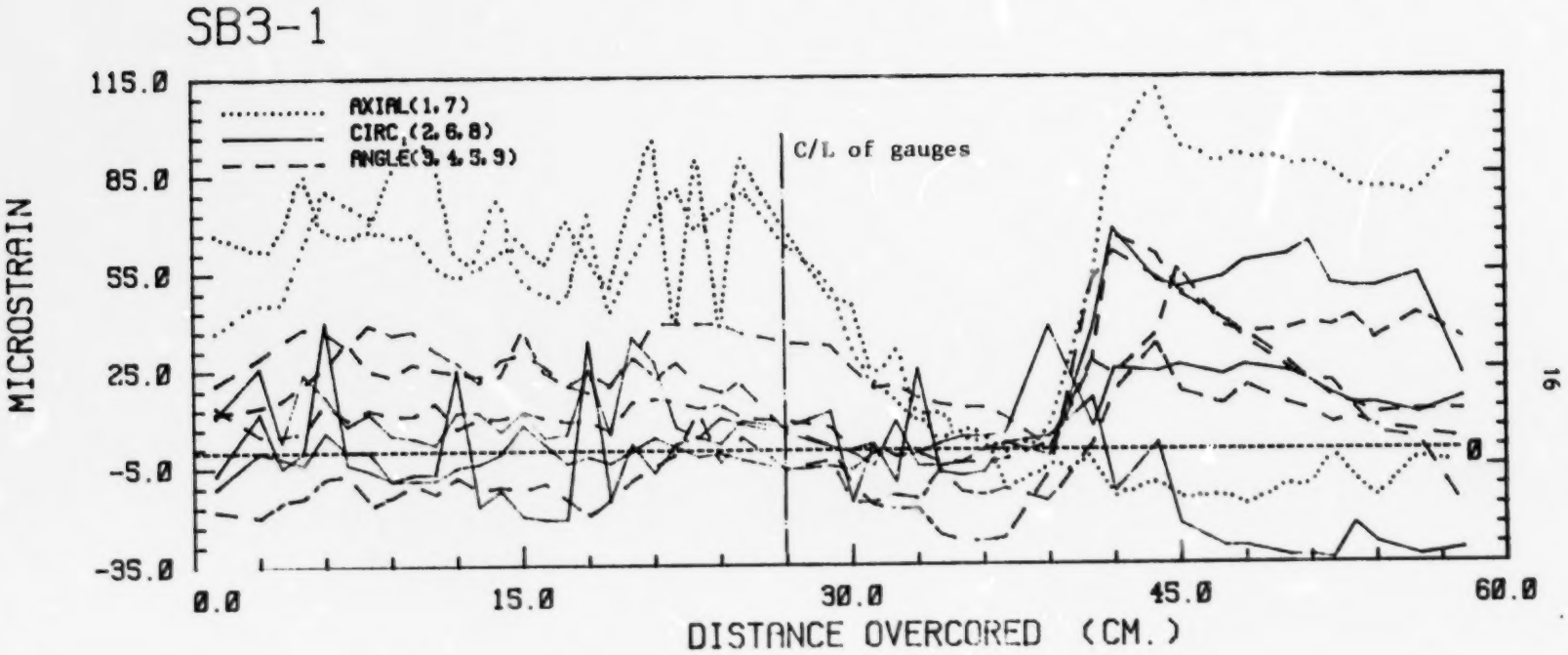


Fig. 9 - Overcoring response of gauges in test No. SB3-1, on the 70 level.

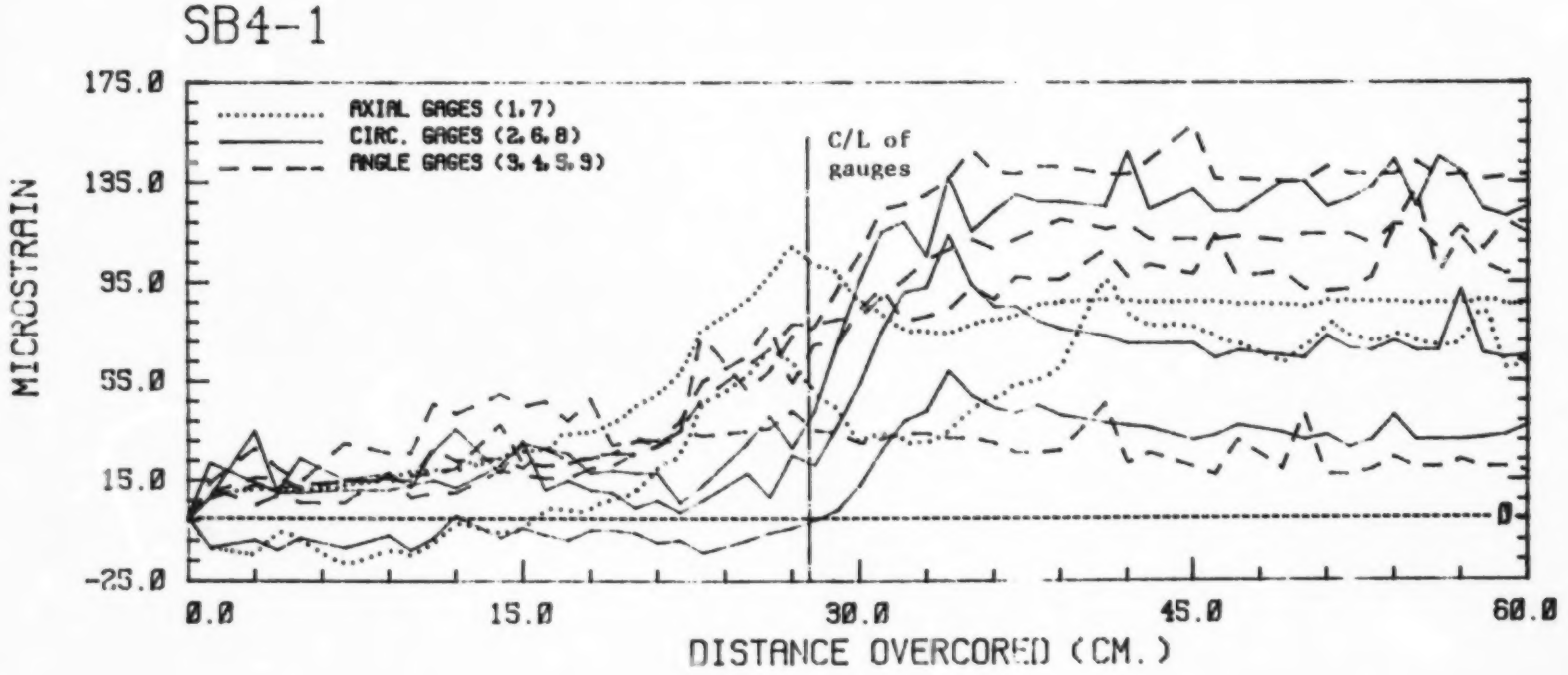


Fig. 10 - Overcoring response of gauges in test No. SB4-1 on the 180 level.

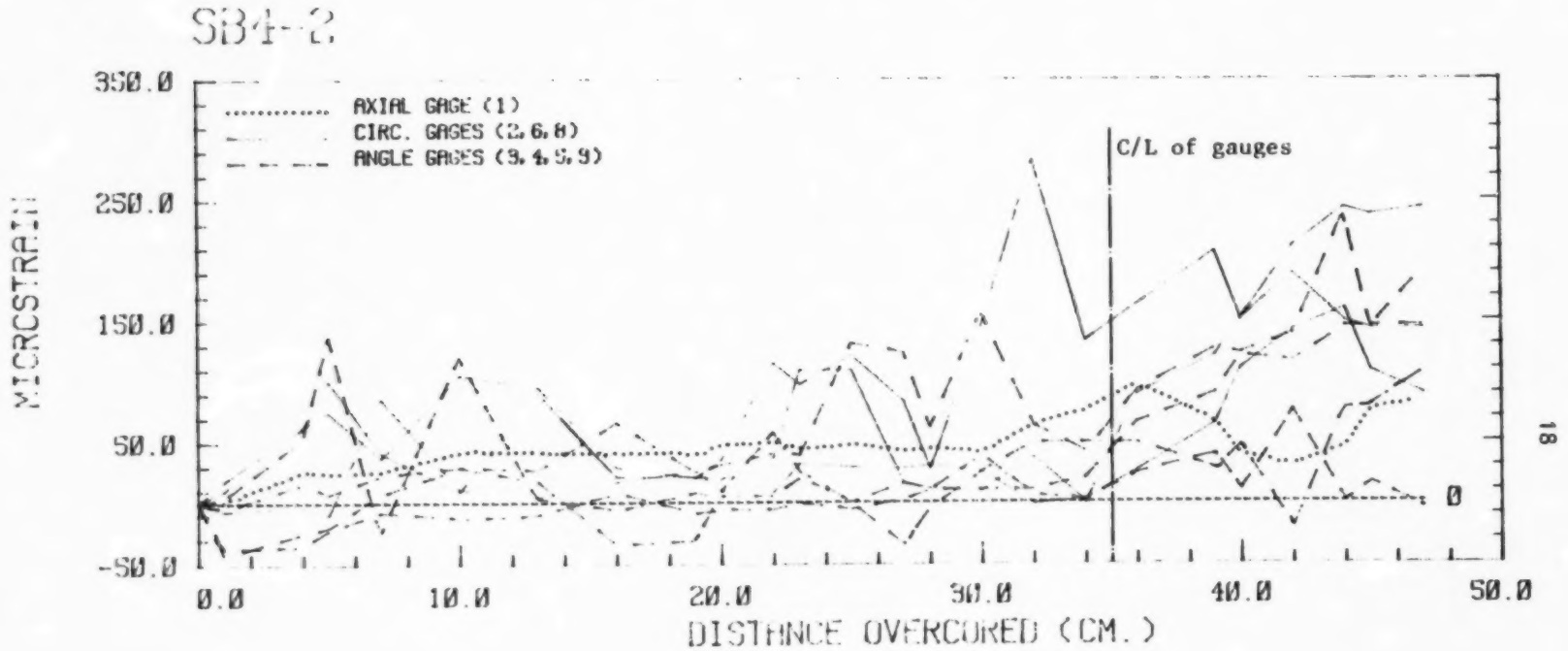


Fig. 11 - Overcoring response of gauges in test No. SB4-2 on the 180 level.

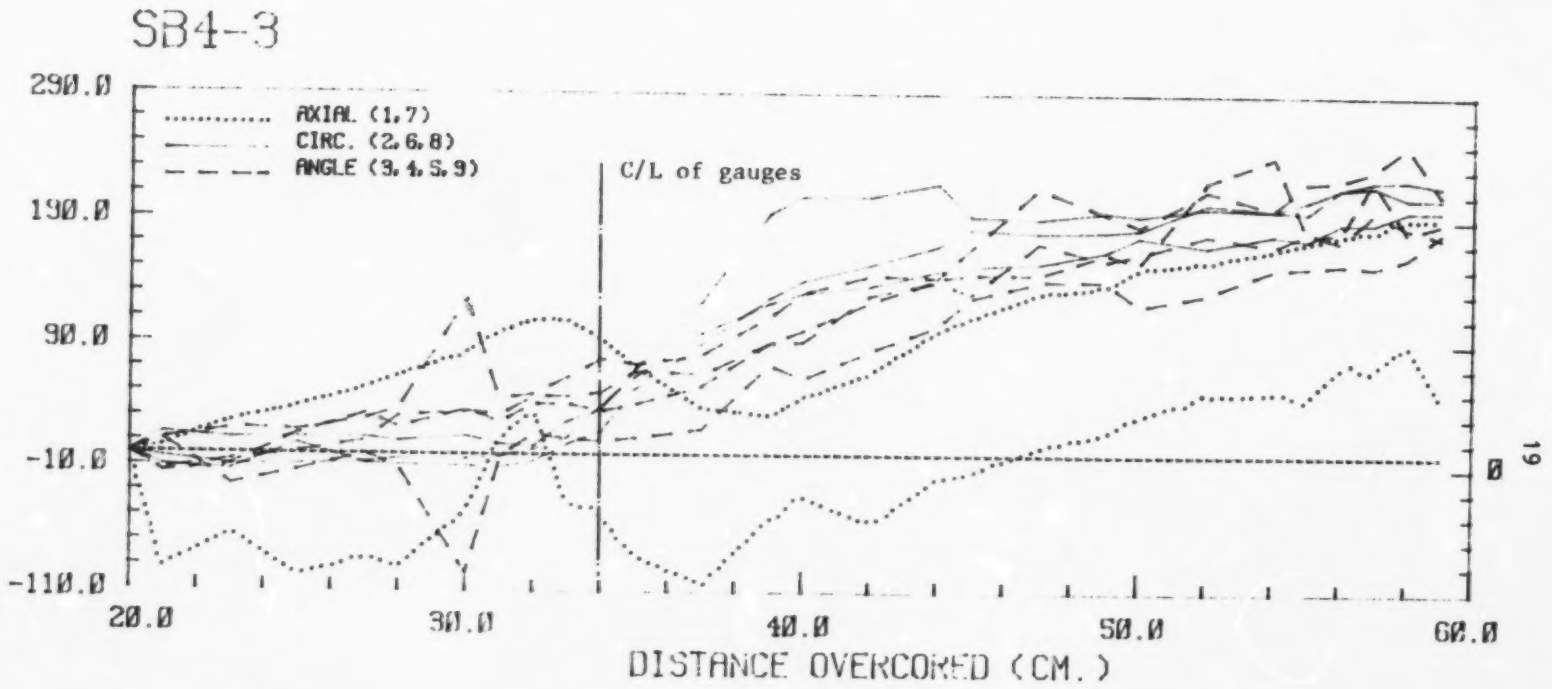


Fig. 12 - Overcoring response of gauges in test No. SB4-3 on the 180 level.

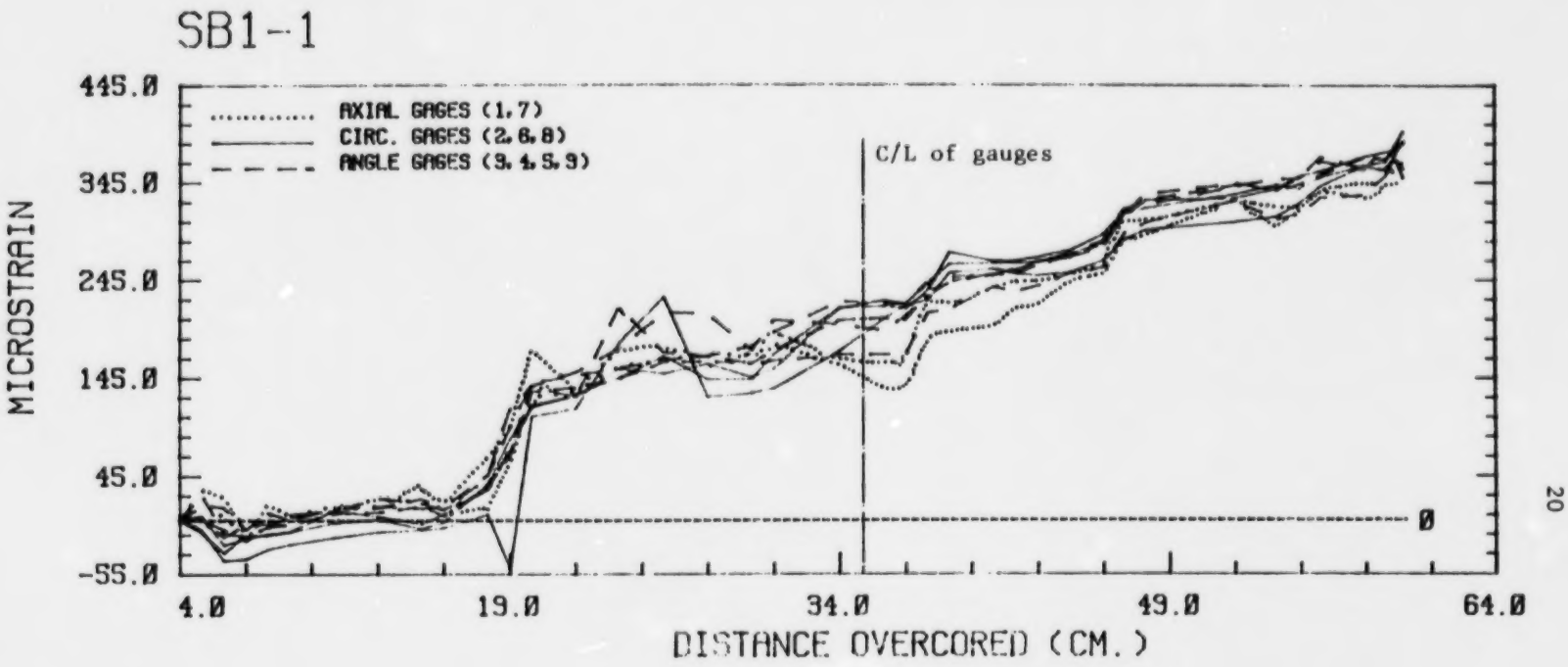


Fig. 13 - Overcoring response of gauges in test No. SB1-1 on the 290 level.

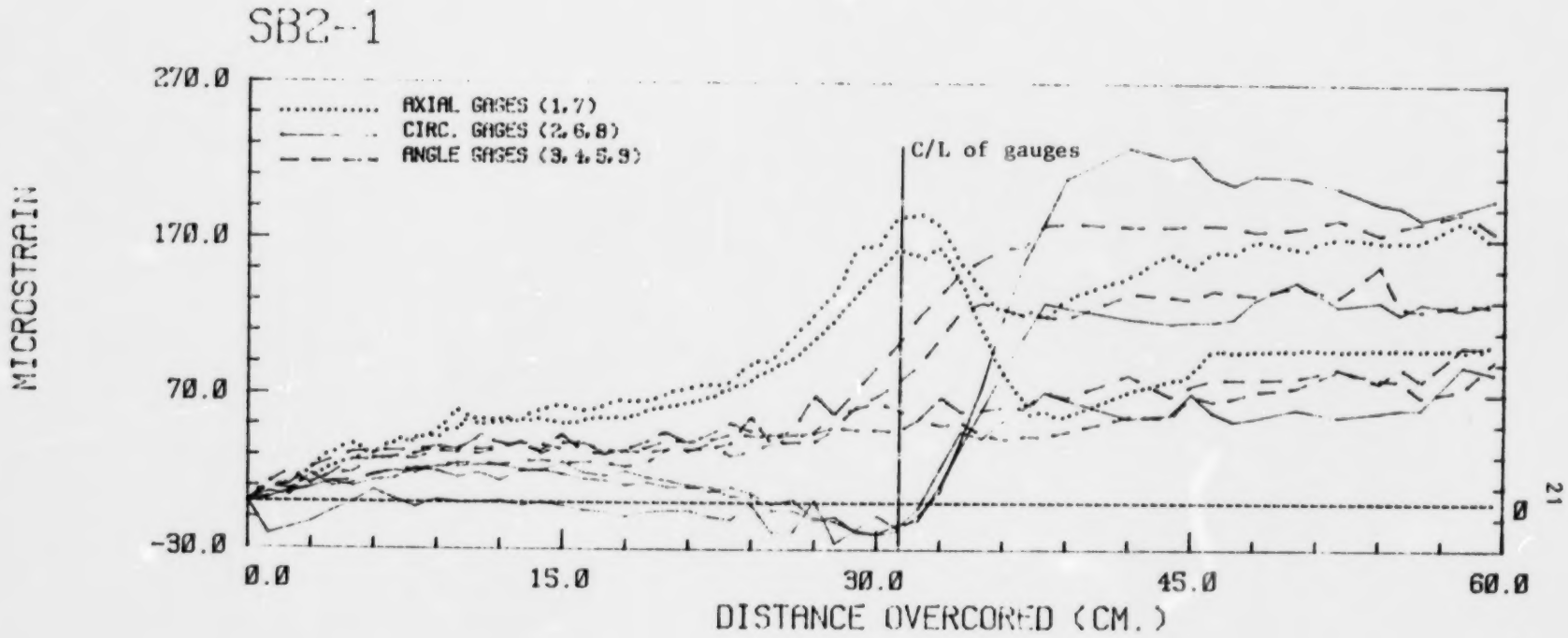


Fig. 14 - Overcoring response of gauges in test No. SB2-1 on the 290 level.

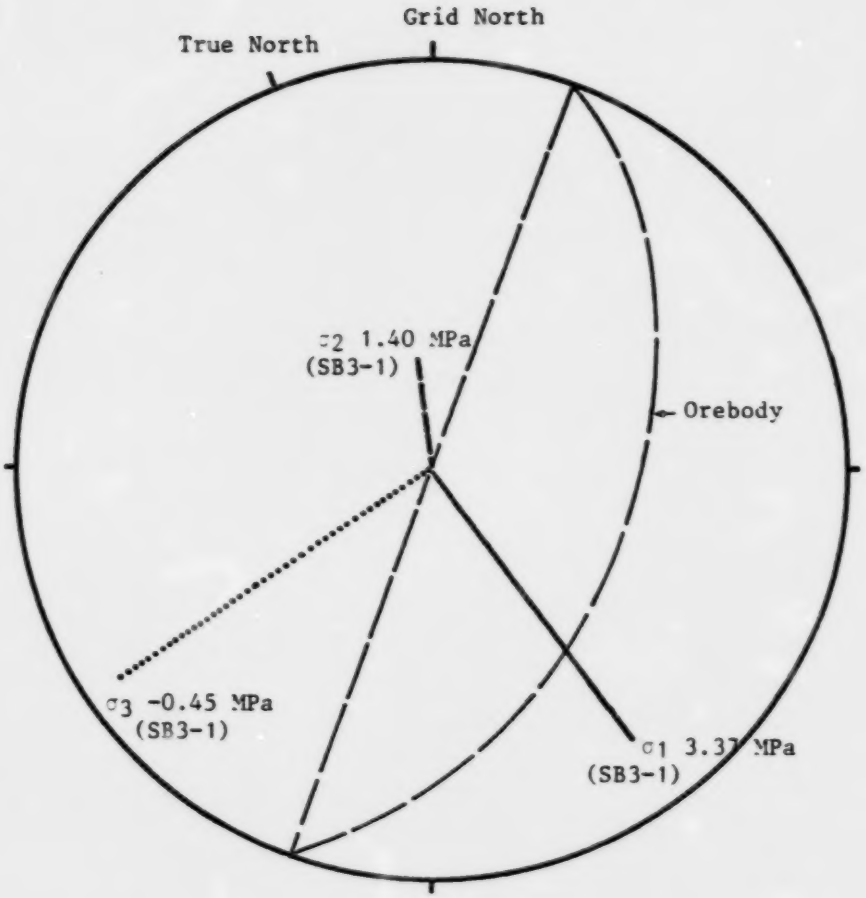


Fig. 15 - Orientation (bearing/dip) of principal stresses from Grid North on the 70 level in equal area net, lower hemisphere projection.

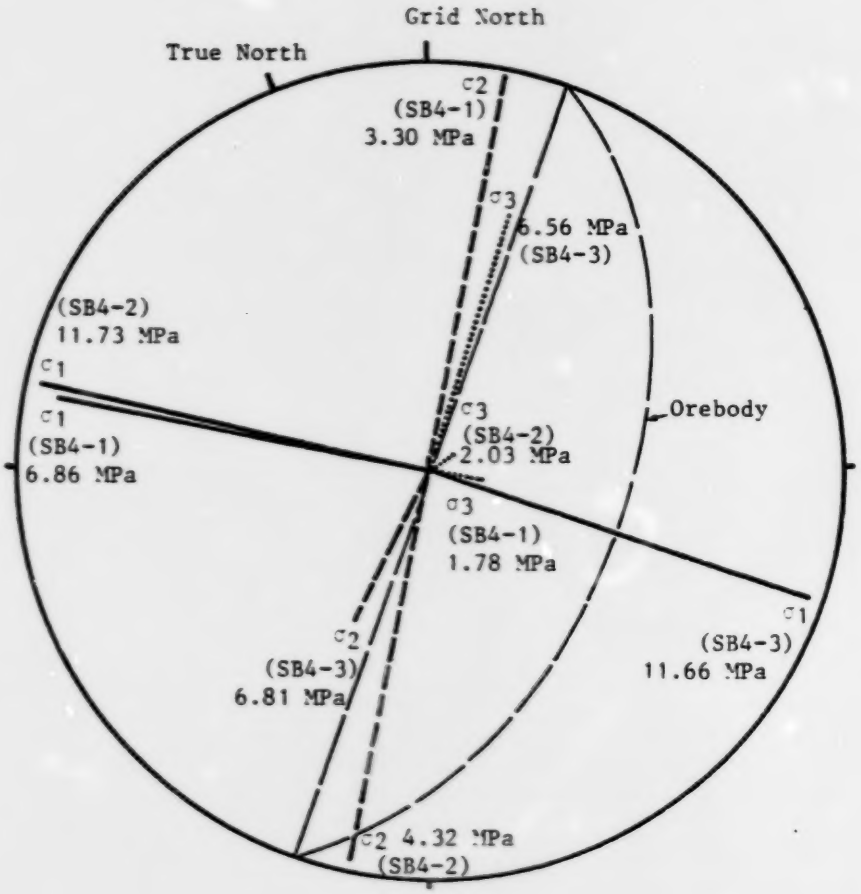


Fig. 16 - Orientation (bearing/dip) of principal stresses from Grid North on the 180 level in equal area net, lower hemisphere projection.

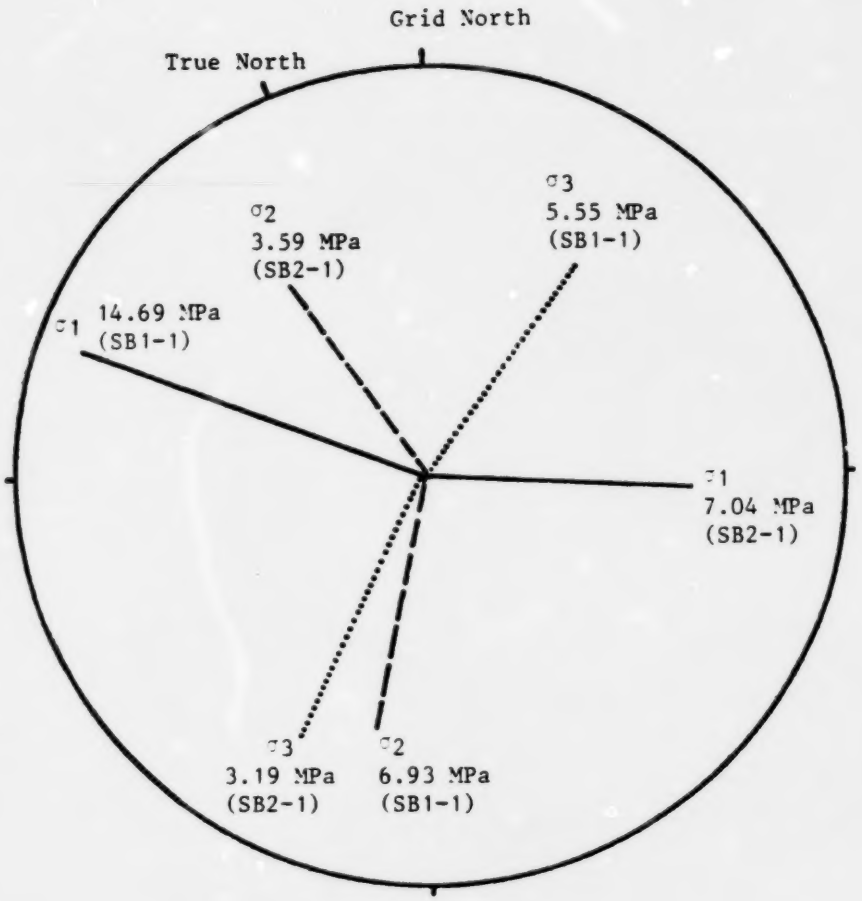


Fig. 17 - Orientation (bearing/dip) of principal stresses from Grid North on the 290 level in equal area net, lower hemisphere projection.

DISCUSSION OF RESULTS

Some gauges yielded erratic responses and were omitted from the stress calculations.

Test results from the 180 and 290 levels are comparable, but the values obtained on the 70 level indicate a different direction of principal stresses, and a higher horizontal N-S than E-W stress. This anomaly in the stress field is supported by the unfavourable test condition, and the presence of a fracture with infilling material located in the overcored sample, crossing through the strain cell.

The strain loss and low strain recoveries in the SB2-1 test on the 290 level was apparently caused by poor bonding of the strain cell on the borehole surface. Therefore, test SB1-1 is the most acceptable one with regard to the stress values obtained and the test performance.

There is some indication that the maximum principal compressive stress increases with depth, but the intermediate and minimum principal compressive stress measurements showed significant scatter. The scatter in the measurements is not unexpected, because of the inhomogeneous geological environment.

The rock properties tests indicated homogeneous rock, with the differences in elastic modulus and Poisson's ratio being insignificant. The variation in elastic strain recoveries at the test sites was probably caused by the existence of joints, rather than by minor differences in the elastic constants.

The standard errors were generally low, with a range of 0.0 to 0.1 MPa.

Regarding test performance and the analysis of the validity of the measurements, the unsatisfactory data obtained from SB2-1 and SB4-2 tests were excluded from the final evaluation. The values of the stress field can be summarized as follows:

Depth (m)	Stress Components (MPa) Horizontal E-W	N-S	Vertical	Principal Compressive Stresses (MPa) Major σ_1	Intermediate σ_2	Minor σ_3
70	0.80	1.97	1.55	3.37	1.40	-0.45
180	*8.82	5.30	4.36	9.26	5.05	4.17
290	13.31	7.45	6.40	14.69	6.93	5.55

* Mean values of SB4-1 and SB4-3 tests.

CONCLUSIONS

From the compilation of ground stress determinations and available data the following major points can be established:

1. The stress magnitudes obtained were similar to those found elsewhere in the Canadian Shield (4,5).
2. The results obtained on the 70 level, indicating a higher horizontal N-S than E-W stress with some deviations in the orientation of principal stresses, did not confirm the existing stress obtained on 180 and 290 levels.
3. On the 180 and 290 levels the major principal compressive stress is oriented nearly E-W and is 3° to 12° from horizontal. The direction of intermediate principal compressive stress is NNE-SSW, whereas the orientation of minor principal compressive stress is not constant. The magnitude of horizontal E-W stress is almost twice the N-S stress and a ratio of the average horizontal stress to vertical stress of 1.62 exists.
4. The measured vertical stress was found to be 10 to 20% lower than the predicted pre-mining overburden stress.
5. In general, regarding the orientation of the orebody, the major principal stress is perpendicular while the intermediate principal stress parallels the orebody. The direction of the minor principal stress to the

orebody is not consistent.

6. The results of the structural survey in the vicinity of the test sites revealed dominant, steeply dipping, discontinuities with a concentration of strikes in NW-SE, NE-SW and northerly directions. An interpretation of the data indicates that, in general, the direction of the current stress field tends to be parallel to the prevailing orientation of geological structures. It remains to be seen to what extent a relationship between the orientations of the joint systems and the directions of the principal stresses exists.
7. Regarding the structural geological evidence and the observed differences in rock material, it appears that the stress distribution in the footwall, orebody and hanging wall at the mine site is not unique. It is, therefore, recommended that caution be exercised when extrapolating the present ground stress values, which were obtained in the footwall, to areas in the orebody or hanging wall.
8. For numerical modelling techniques it is required to input the pre-mining vertical stress, as well as the horizontal stresses perpendicular and parallel to the orebody. From these stress measurements the most suitable input stresses are:

$$\sigma \text{ vertical} = 0.025\ MN/m^3 \times \text{depth (m) in MPa}$$

$$\text{perpendicular } \sigma \text{ horizontal} = 2.0 \times \text{vertical stress}$$

$$\text{parallel } \sigma \text{ horizontal} = 1.1 \times \text{vertical stress.}$$

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